MAGNETOSPHERIC SHORTCOMINGS IN IONOSPHERIC - MAGNETOSPHERIC COUPLING: AN IONOSPHERIC PERSPECTIVE

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ABSTRACT

The ionosphere, on a global scale, is reasonably well understood from a climatology perspective. However, the storm dynamics of the ionosphere are not fully understood. This partly arises from the complex response function of the Thermosphere-Ionosphere (T-I) system but also from the uncertainty in the space and time dynamics of the magnetospheric inputs to the ionosphere. In the context of M-I coupling, the ionosphere responds to magnetospheric electrodynamic forcing by altering the conductivity in the ionosphere and by plasma transport. Phenomenologically, we understand how to let the ionospheric conductivity evolve in response to local precipitation and how to transport plasma in the collision media of the thermosphere, but we are unable to complete the global coupling because the magnetospheric drivers cannot be defined on the appropriate scales.

The magnetospheric drivers in question are the magnetospheric electric field and the particle (auroral) precipitation. A need for dynamic models of both these drivers exists. Unfortunately, no eminent theoretical, magnetospheric breakthrough is likely which would enable these sources to be defined from knowledge of a few solar wind parameters (e.g. a magnetospheric convection model that responds to IMF and solar wind pressure changes as well as the ensuing storm and substorm dynamics). Hence, it rests upon improved observation techniques and data handling to make progress in the M-I coupling issue. Specific suggestions are to use more global imagers to monitor the precipitation in order to infer boundary locations and particle energy input and to make extensive in situ observations of the plasma convection on a global scale. The Motorola Iridium project with its 77 polar satellites at ~800 km altitude would be an ideal platform for this latter objective.

1. INTRODUCTION

The objective of this brief paper is to give an ionospheric perspective on the status of magnetosphere-ionosphere (M-I) coupling. Specifically, to focus on the magnetospheric limitations. Since the meeting is focussed on how to improve applications of the solar terrestrial environment, these limitations are cast in a "bottom-line" manner. At this time, ionospheric understanding at the > 10 km to global scale is, from the climatological stand-point, well understood (Schunk, 1987, Sojka, 1989, Rodger et al., 1992). The extension to storm and M-I coupling is, to a large extent, limited by our understanding of the magnetosphere. Both the magnetospheric electric field and auroral precipitation are only modeled at a climatological level. Yet these are the principle drivers in the M-I coupling and ionospheric storm systems. Section 2 describes the ionosphere dependence upon the magnetosphere and the limitations in these magnetospheric inputs. Section 3 discusses the possible solutions and the relative importance of making these improvements. Section 4 briefly makes recommendations from the ionospheric perspective.

2. KEY MAGNETOSPHERIC LIMITATIONS IN M-I COUPLING

The ionosphere depends upon the neutral atmosphere, both its density and wind, the solar EUV spectrum, and the magnetosphere. During disturbed periods, geomagnetic storms and substorms, it is the magnetospheric inputs which drive the ionosphere and the thermosphere. Figure 1 indicates the specific magnetospheric processes that affect and drive the ionosphere. The convection electric field provides momentum and energy to the ionosphere while the auroral precipitation supplies energy and also ionization. Secondary to these two processes is the electron heat flux and the Birkland currents. The heat flux can dramatically affect the ionospheric topside scale height while the currents can, through the electron energy equation, also heat or cool the ionospheric plasma. The order of the four processes listed in Figure 1 is consistent with their respective impact upon the ionosphere during storms and substorms. Unfortunately, our understanding of how these processes vary during storms and substorms tends to be only "climatological." In the past decade the satellite borne auroral images, i.e., DE-1 and Viking have offered an opportunity to change this, however, we are still without a storm or substorm auroral model. As indicated in Figure 1, there is a need for dynamic models of the magnetospheric electric field and auroral precipitation.

- Magnetospheric Inputs to the Ionosphere
  - (1) Convection Electric Field
  - (2) Auroral Precipitation
  - (3) Electron Heat Flux
  - (4) Currents (indirectly)
- These are the $\boxed{\text{DRIVERS}}$ of ionospheric <u>storms</u> and <u>weather</u>.
- At present only have climatological (statistical) models.
- Need storm and weather models of items (1) through (4).

Figure 1. Magnetospheric inputs to the ionosphere.

Figure 2 looks at the present status of how these magnetospheric inputs are represented in different levels of ionospheric research. The climatological level using statistical models is not unreasonable. However, during storms and worse still in the case of substorms (weather), the representation of magnetospheric inputs is very poor. During large storms, data from satellites and ground based facilities are used to adjust the statistical models. This procedure requires extensive data collection and analysis to make even small changes to the inputs. In the case of substorms, very little data is available. Data from incoherent and coherent scatter radar can give good resolution 2-D data, however, only at specific locations and at certain times. Satellites produce limited in situ data, although images of the auroral precipitation have demonstrated that very good 2-D time-dependent substorm representations are possible.

Condition		Magnetospheric representation		Status
Climatology	→	Statistical inputs	→	satisfactory
Storms	→	Tune Statistical Inputs with indices, DMSP, images, radars, etc.	→	months after the event, research level.
Weather	→	ISR local 2D measurements of (1) & (2)	→	very limited

Figure 2. Present day status of how magnetospheric inputs are handled in an ionospheric model.

3. DISCUSSION

Since most of the interest in M-I coupling lies in the possible feedback processes, it is necessary to have magnetospheric and ionospheric models that respond to changes in their mutual interaction. At this time, ionospheric models exist which will respond to changes in the electric fields and particle precipitation. These changes can be on a global scale (Sojka et al., 1992; Fuller-Rowell et al., 1991) or on smaller arc scales (Crain et al., 1992). In each case the ionospheric model will generate new plasma distribution which are based upon the appropriate physics. These changes are then manifested in the form of conductivity changes, either in magnitude or more subtly in the ratio of the Hall to Pedersen conductivity (Crain et al., 1992). It is these changes that cause feedback to the magnetosphere in a non-passive manner, i.e., the changing conductivities not only imperfectly reflect Alfvén waves but they generate secondary Alfvén waves (Zhu and Kan, 1990; Lysak, 1991; Zhu et al., 1992). At this time, the ionospheric models can readily handle magnetospheric changes in the convection electric field and auroral precipitation on spatial scales as small as 20 to 100 km and times as short as 10's of seconds.

The basic difficulty in carrying out M-I coupling is representing the convection electric field and auroral precipitation on these scales. Although the auroral images can potentially represent the auroral input on these scales, the electric field would still remain unknown. Most M-I coupling work to date has been based on 2-D simulation of very local arcs (Miura and Sato, 1980; Rothwell et al., 1988). This work involves solving a suitable set of MHD equations. To date, these equations tend to assume that the ionosphere is a passive load, i.e., not the dynamic one discussed above. The work of Zhu et al., (1992) have introduced a variable load and consequently, significantly different coupling physics is obtained. For global scale 3-D modelling, the ionosphere is usually regarded as a coarse static load (Walker et al., 1987). However, attempts are being made to overcome this limitation. However, in a global MHD model this is extremely difficult since it involves a significant increase in computational resources which are already at the limit of technology.

Hence, it is unlikely that "useable" weather models of the electric field or the auroral precipitation on the desired scales will be forthcoming in the short term from these theoretical developments. Each of these MHD models produces extremely complex electric field and precipitation data sets. At this time, the analysis of such data sets is at an extremely primitive research level. The parameterization of these data sets is clearly a future goal but at this time no time scale for such products is available.

- Predictive Magnetospheric Modelling of (1) and (2) [possibly (3)] are needed.
  - a) So that electric fields and precipitation can be coupled correctly in ionospheric models.
  - b) So that storm phases can be induced in ionospheric models.
  - c) Feedback with the ionosphere is probably crucial in determining these solutions.
  - d) In reality this is a long way away.
- What is really needed is a representation of (1) and (2) at, say 800 km, with comparable spatial and temporal resolution. Imag[illegible] can be used for (2).
- Need some way of deducing E globally on the same time and spatial scale. Combine all observations in assimilative mapping of ionospheric electrodynamics (AMIE) software to produce electric field patterns, but this needs more data!

Figure 3. Recommendations for advancing the magnetospheric inputs from climatological to dynamic models.

The alternative is to look at extended observation programs to produce the required models. Figure 3 summaries the bottom line of our present day capability and its extrapolation into the near future. In this figure we have referred to the magnetospheric electric field, auroral precipitation, and magnetospheric heat flux as items 1, 2, and 3, respectively. This is the order of importance outlined in Figure 1. Figure 3 indicates that for practical purposes the best hope of improving our understanding of the M-I coupling is to obtain more extensive empirical data. This means that the auroral images, which define the dynamics of the auroral precipitation must be augmented with more extensive maps of the convection electric field, especially the temporal dynamics of how the convection electric field changes with time during storms.

Since the majority of the energy in the global ionosphere-thermosphere system comes from Joule (frictional) heating, it is important that our observations of the electric field evolution improves. At the present time, we have developed all the required components of a feasible operational system. Ground based observations from coherent and incoherent scatter radars measure plasma drifts. Satellite borne probes measure in situ plasma drifts or the electric fields.

Ground based magnetometer networks measure magnetic changes due to the ionospheric current system. All these data can be combined in a generalized Ohm's law procedure to produce the best global convection and current system. This inversion procedure needs a global conductivity map, which ideally would be derived from a global auroral image. One particular example of this procedure is the NCAR AMIE program (Richmond and Kamide, 1988; Kamide et al., 1981). At this time, AMIE is a research tool. With the best present day availability of observational data AMIE is still data starved. Significantly, more data are required on a more uniform global scale.

4. RECOMMENDATIONS

The lack of dynamical models of the magnetospheric convection and auroral precipitation is a major limiting factor in M-I coupling and ionospheric modeling of storm periods. Since theoretical developments are not eminent, other solutions are needed. Two observational solutions are potentially available to augment the present day statistical models.

1) Global scale auroral images define not only auroral boundaries, but have spatial and temporal resolution better than storm dynamic scales. These images should be sought after for application uses.
2) More extensive in situ electric field or plasma drift data is needed. These data must be on a more uniform global grid rather than clustered in a few locations. The applicational uses for these data do not require state-of-the-art instrumentation. In this instance, a "cheap-and-many" is better than a "one-bigger-and-better" implementation scenario. The proposed 77 Motorola Iridium satellites would be an ideal platform for such sensors. The data is real time, globally distributed, and has highest density of coverage in the poles.
3) Data from 1 and 2 above should be analyzed in conjunction with other ground based radar and magnetometer data through a generalized Ohm's law inversion technique to provide the best global electrodynamics representations.

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